*Jochen Jirmann, DB 1 NV*

# Voltage - Controlled Tuned Wideband Oscillators

**For many measurements frequently undertaken in amateur practice, such as the tuning of filters or antennas, a signal source is required which is capable of being tuned to the limits of the amateur band concerned and beyond it. If a commercial sweep generator is not available, a suitable sweep oscillator can be made without too much difficulty. This article should help to dispel the myth of a black art surrounding this type of circuit by explaining the techniques involved and also assist in its construction.**

## 1. INTRODUCTION

The usual practice in amateur equipment is to try and limit the tuning range of the voltage - controlled oscillator (VCO) of the synthesizer as much as possible, in order to mitigate the unavoidable effects of the high oscillator noise pedestal and the not negligible effects of the tuning voltage noise. Suitable circuits have appeared in various publications and the work of DJ 7 VY is well known in this area. In amateur test practice, oscillators are required which can be tuned over a large bandwidth, whether it be to determine the impedance of wideband antennas, the tuning of harmonic filters etc. or as a local oscillator in a superhet receiver. This article will introduce a few circuits which may be employed as wideband VCOs and which will substitute for many of the purposes for which a commercial sweep generator is used.

The author would like, in particular, to encourage the reader to make some experiments as the test equipment required is held to reasonable limits. Two 12 V DC power supplies are required together with a 0 - 30 V variable supply. An RF power meter (or at least a power indicator) and a frequency counter should complete the list of equipment necessary. If a UHF counter is not available, an ECL prescaler such as those found in TV tuners, costing about DM 20, may be added to the counter thus extending its range from 10 or 20 MHz into the region of 1 GHz. Suitable types are e. g.: The Telefunken U 264 / U 664 (divide by 64), the U 666 (divide by 256) or the Siemens SDA 2211 (divide by 64). There are many circuits in amateur publications which deal with the way in which the decimal point may be inserted at the correct point on the indicator read-out following the addition of the prescaler. If the exact tuning voltage for a particular frequency is desired to be known, then a digital voltmeter will also be necessary.

In order to keep the parasitic reactances to as low an order as possible, the conventional printed circuit board techniques must be dispensed with. Instead coupling and blocking disc capacitors, using components without wire connections, the circuits are soldered directly to the ground plane or circuit tracks of the PCB. They are also used as support tags for other components. The photographs of **fig. 3** show that disc ceramics can be soldered directly to the walls of tin-plate screening boxes as well as on PCB copper. In order to ensure a high Q in tuned circuits, it will always be preferable to employ ground areas made from copper or silver coated copper. A suitable preparation should also be used to counter the effects of copper oxidation and solder flux corrosion.

## 2. COMPONENTS

Professional wideband techniques mostly employ YIG oscillators whose frequency determining element consists of a chip of yttrium-iron-garnet. The intrinsic frequency of the YIG chip can be varied over a few frequency octaves by the application of an external magnetic field.

When such components became too expensive for amateur purposes, a substitute had to be found. The basic requirements for the family of oscillators described here ar as follows: –

- Frequency range of interest from 100 MHz to 1 GHz
- Each oscillator must tune over a band of 0.5 to 1 octave
- Output power of greater than 1 mW
- Tuning voltage 0 to 30 V
- Output power variation over tuning range: less than 6 dB
- Harmonic content: less than 20 dB
- Where possible a buffer stage should be incorporated

Narrow-band oscillators may be readily use barrier FETs to deliver particularly noise-free signals. FETs have, however, the disadvantage that they possess a relatively large input capacitance (5 pF) which lies directly across the frequency determining resonant circuit, effectively limiting the tuning range. The transconductance of FETs, in relation to bipolar devices, is relatively small and therefore the effects of this input capacitance cannot be reduced by looser coupling to the tank circuit.

Bipolar transistors, on the other hand, have an output capacitance of under 1 pF and are, in spite of their worse noise characteristics, more suitable for wideband oscillators than FETs. Experiments have shown, moreover, that a transistor having a higher transit frequency performs no better, in this application, than one which only just meets the frequency specification. In general, it is sufficient to choose a transistor which has a transit frequency of 1.5 to 2 times the intended working frequency of the circuit. In television tuners, working below 1 GHz, the preferred PNP oscillator transistors are as usually those such as the BF 970, and BF 979. Above 1 GHz the low-cost BFW 92 and the BFR 90 have proved well suitable. In any case, suitable transistors may be found by experimentation and it is surprising that many are to be found in the ranks of "general purpose transistors".

In all wideband oscillators, a careful control of parasitic oscillations, arising in coupling and tank circuits, must be undertaken as these lead to unpredictable tuning characteristics. The control of parasitic oscillations is always more difficult as the frequency increases. All circuits are therefore designed so that the tuned circuit is grounded on one side and the oscillator supply voltage can be directed via this to the active device. This avoids the use of the critical radio frequency choke (RFC) in the collector and non-critical resistors may be employed both to set the transistor working point and for decoupling purposes. PNP transistors allow a particularly simple form of construction using a positive supply voltage.

In the frequency range 500 to 1000 MHz, normal UHF tuner diodes, such as the BB 105, BB 505 or similar, may be used. They offer a tuning capacitor ratio of about 5 which ensures an octave coverage providing that the resonator tuned circuit capacitance is kept low.

At lower frequencies, the hyperabrupt types used in cable TV tuners, such as the BB 609, are suitable. These have a capacitance ratio of 13 which allows a tuning range of 2.5 to 1 to be possible. As the Q of these diodes is quite low in the UHF region, they should not be employed higher than 300 MHz.

The UHF diodes around 1 GHz and above, which have plastic or glass encapsulation, are hardly usable owing to a series inductance of some 3 nH. The self-resonance of a BB 105 lies, according to the barrier voltage, between 750 MHz and 2 GHz. Surprisingly, they have been employed in the latest UHF tuners in the form of MiniMELF diodes for surface mounting. The Intermetall BB 621, owing to its construction and low series inductance, has a very good Q at frequencies over 1 GHz. The following examples of circuits will show that this diode may be employed in circuits up to 2 GHz.

## 3. BASIC CIRCUITS

The choice of suitable oscillator circuits which, with very little alternation, are able to be used on the various frequencies of interest, is all that remains. There are two basic oscillator principles which come into consideration, the two-terminal and the four-terminal oscillator circuits. The four-terminal oscillator uses the transistor as an amplifier and connects input and output together via a tuned circuit. The two-terminal oscillator uses the transistor as a negative resistance which counters the losses in the tuned circuit. This type of circuit works as well at very high frequencies because the transistor's internal capacitance is used as part of the feedback mechanism.

Now that the basic types have been explained, a few examples of circuits for various frequency ranges will be introduced.

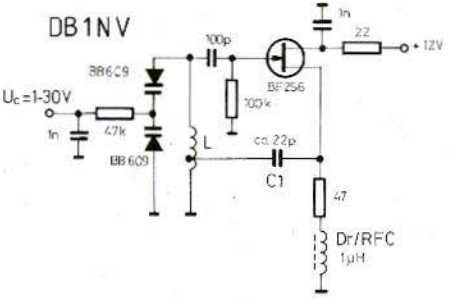


**Fig. 1: A FET Oscillator in an inductive three-terminal circuit.**
**Frequency range: 150 to 300 MHz**
**L: 3 turns (length 7 mm approx.) int. dia = 7 mm**
**tap: ½ turn from ground end**
**Output coupling: loop about ½ turn from ground end**

## 4. PRACTICAL CIRCUITS

### 4.1. A FET Oscillator for Frequencies up to 300 MHz

The circuit of **fig.1** shows a tapped inductor circuit with the BF 256 FET connected in a drain driven manner. As the input capacitance of the FET is in the region of 5 pF, a tuning range of only one octave is possible despite the use of a hyperabrupt varicap diode.

An important circuit detail is the capacitor phase shifter C 1 connected between the source and the DC blocking and as the FET operates as a source follower the input voltage at the gate and the output voltage should be in phase. At the frequency under consideration i. e. above 100 MHz, this assumption is no longer valid and the source voltage phase shift must be compensated by using a (too) small coupling capacitor. Owing to the large range to be covered, the value of this capacitor must be only a compromise chosen on the basis of the output power remaining reasonably constant over the tuning range. It is possible to employ another varicap here in order that the feedback phase shift compensation may vary with frequency. This idea was not persuad in the interests of developing a circuit which would be readily reproducible.

This circuit is only intended for applications where

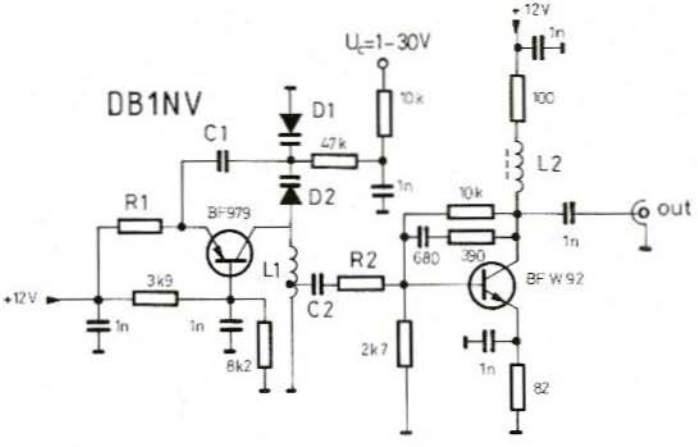


**Fig. 2:**
**An 80 to 1000 MHz bipolar oscillator, components as in table 1**

a really noise-free signal is required and where the tuning range need not be too large. The oscillator of **fig. 2** was dimensioned for a frequency range of 150 to 300 MHz.

The following bipolar oscillator is intended for universal application at frequencies between 80 and 1000 MHz in three bands. With a curtailment in performance it may be made to operate at frequencies up to 1.3 GHz.

### 4.2. A Bipolar Oscillator for 80 to 1000 MHz

The oscillator shown in **fig. 2** represents a capacitive three-point circuit which does not require a tapping on the oscillatory tuned circuit in order to sustain oscillation. The transistor, a PNP BF 979 or BF 479, works in a commonbase circuit with the collector being effectively at ground potential with the tuned circuit.

| Frequency range | R 1 | R 2 | C 1 | C 2 | L 1 L 2 | |
|---|---|---|---|---|---|---|
| 80 to 200 MHz | 390 | 39 | 68 p | 47 p | 7.5 turns, 4 mm Ø F 100 - core tapped near ground end | choke 33 $\mu$H |
| 200 to 500 MHz | 390 | 120 | 22 p | 47 p | 3.5 turns, 4 mm Ø length approx. 8 mm, tapped near ground end | choke 22 $\mu$H |
| 500 to 1000 MHz | 220 | 22 | 6p8 | 2p2 | strip 15 x 3 and 3 mm above ground, tapped 3 mm from ground end | choke 4.7 $\mu$H |

**Table 1**

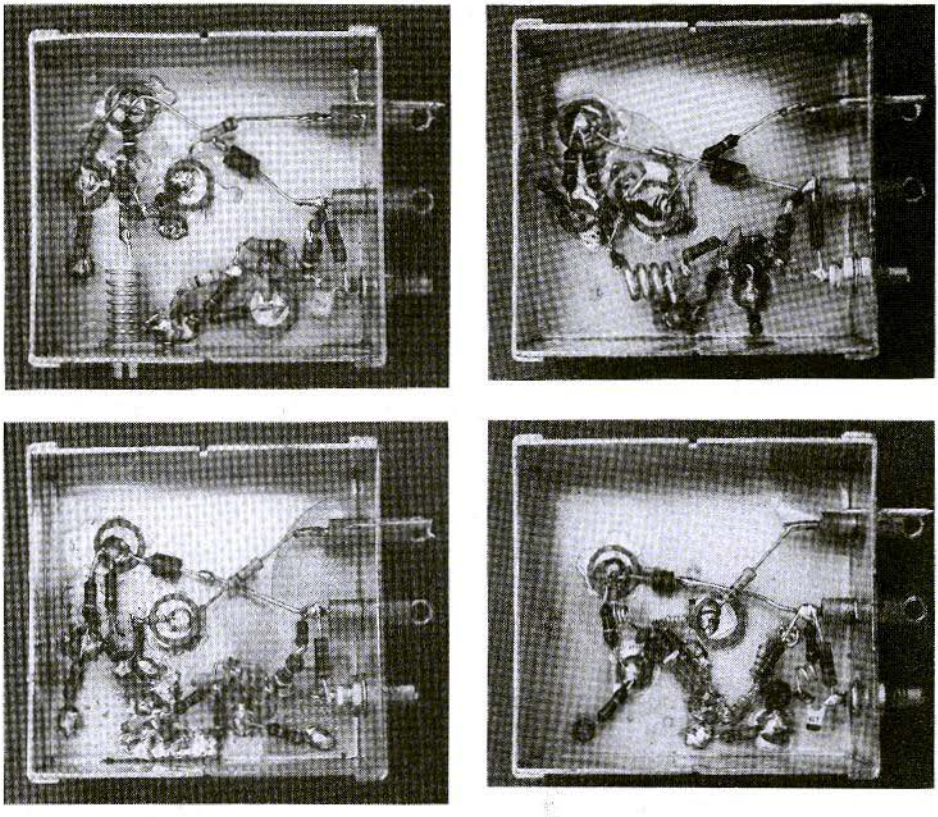

**Fig. 3: The author's prototype constructions**

The capacitive divider forming the feedback circuit is composed of two varicap diodes together with the coupling capacitor C 1. The latter also compensates for the phase shift through the transistor.

The frequency determining circuit has an air-cored coil inductor for the frequency ranges 80 to 200 MHz and 200 to 500 MHz and a conductive strip inductor supported above the PCB plane for the range 500 to 1000 MHz. The tapping on the tuned circuit inductor controls the degree of coupling to the buffer stage which, in turn, affects the degree to which the oscillator frequency is pulled by HF output load variations. The tapping point also affects the bandwidth, the Q and therefore the harmonic content as well as the output level. If a low harmonic content is required, the coupling must be kept very low i. e. the tapping point near the earthy end of the inductor in order that the buffer stage is not driven too hard.

The important characteristics of the oscillator are summarized in **table 1** and the photograph of **fig. 3** shows the prototypes constructed by the author for the bands 80 to 200, 200 to 500, 500 to 1000 and 1000 to 1350 MHz. The last oscillator will not be mentioned further here because it represents the highest frequency possible with this

type of circuit. The oscillator could be dimensioned for the range 30 to 80 MHz by merely increasing the size of the air-cored inductor. The tuning capacitance and self-capacitance should, however, be held to low levels in order that the varicap is able to cover the desired sweep range. The frequency can be further reduced by using medium-wave type varicaps (C = 20 to 500 pF). The constructor should note that the various resistance and capacitance values are changed according to the frequency range of interest. In particular, the high frequency example 500 - 1000 MHz should be constructed with the shortest possible RF leads and the layout, shown in the photograph, closely followed.

### 4.3. Oscillators for the Range 1 to 1.5 GHz

In order to construct VCOs for frequencies higher than 1 GHz, a few decisive circuit alterations were necessary. Firstly, the varicap diodes were replaced by a better type (BB 621). The inductive part of the tuned circuits was too small, physically, to be constructed from strip line (L < 10 mm) and had to be made from λ / 2 resonators, this doubles the length thus making it more manageable. The one end of the resonator line has a varicap diode tuning and the other end has a trimmer to set the lower limit of the frequency range tuning. The upper frequency limit is determined by the residual capacity of the varicap diode. The overall frequency range of this oscillator is not as great as the other versions described earlier, having only a half octave span.

Older readers will, perhaps, be aquainted with the tank circuit of the first tube UHF power amplifiers. The transistor has an earthed collector and driven at HF to a floating emitter. Owing to the transistor's internal feedback via the base-emitter capacitance, it has at the base, as far as HF is concerned, an input resistance having a negative real component which decreases the loading across the tank circuit.

Using a small capacitance, of a fraction of a picofarad at the emitter, this feedback can be optimized. The capacitor can take the form of a 0.5 to 1 cm wire bent to a suitable position above ground.

The HF is coupled out from the base circuit by means of a trimmer. A buffer stage was not used owing to its difficult design and the fact that its effect is not particularly good due to the isolation from output to input of a 1 GHz, simple transistor stage being very small. The use of a circulator was not contemplated on grounds of cost.

The 1 to 1.5 GHz oscillator of **fig. 4** is shown, in prototype construction, in the photograph of **fig. 5**. An experimentally built oscillator, covering 1.7 to 2.4 GHz, displayed a large output power fluctuation when tuned over the range together with poor tuning characteristics and frequency jumps. This, evidently, is the frequency limit for oscillators built with standard components. Expensive glass tubular trimmers are not absolutely necessary for frequencies under about 1.5 GHz, the cheaper teflon-foil ("Sky") trimmers may be

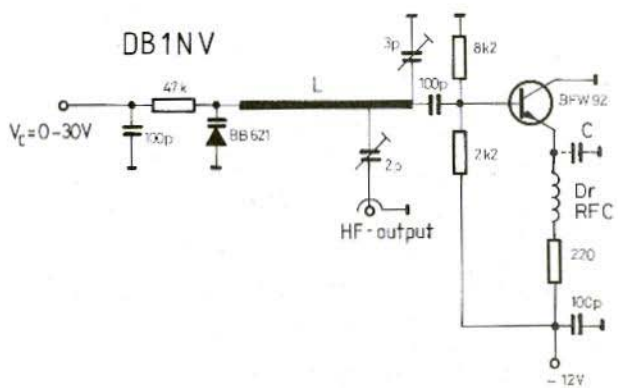


**Fig. 4:**
**A 1 to 1.5 GHz oscillator**

**Fig. 5:**
**The 1 to 1.5 GHz oscillator prototype**

substituted. Further attempts to increase the frequency of this type of oscillator to 3 GHz, by reducing the tank circuit to 5 mm, was not encouraging. Besides the output power varying over the tuning range from 0.1 to 10 mW, there was a tendency to mode-jump, hysteresis effects and similar misfortunes.

### 4.4. A GaAs-FET Oscillator for 1 to 1.6 GHz

After the GaAs-FET, such as the CFY 13, became cheaply available to the radio amateur, it has become possible to use them in the construction of broadband VCOs. As **fig. 6** shows, this circuit is very similar to that of the preceding bipolar oscillator but the resonator is tuned at both ends with varicap diodes. This is facilitated because of the very low load on the resonator imposed by the FET. The HF coupling is carried out by means of a small loop located near a current antinode in the tank circuit. The additional feedback coupling, using the 1 pF capacitor, improves the oscillator starting characteristics at the low end of the frequency range. The drain resistor damps any tendency to parasitic oscillation in the SHF range. The power output of 1 to 2 mW over the range from 1 to 1.6 GHz was achieved with this circuit.

## 5. OBSERVATIONS

In all probability, the first experimental oscillator will not behave quite as well as expected. The following information notes should help to sort out a few possible sources of error: -

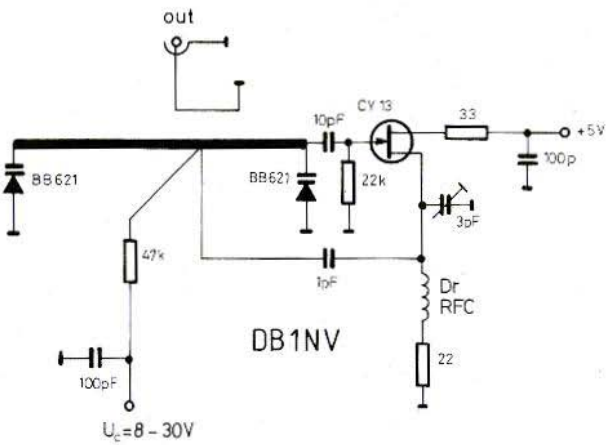


**Fig. 6:**
**A 1 to 1.6 GHz GaAs-FET oscillator, Choke: 3 turns 0.3 CuL, 1.5 mm dia**

- Oscillator refuses to oscillate:
  Load coupling too tight, feedback coupling incorrectly chosen, varicap diode wrongly connected or a transistor defective – the author has often found transistors which tested good under DC conditions but failed at the working frequency.
- Unstable frequency:
  Tuning voltage power supply poorly regulated.
- Sharp drop in output power at band ends:
  Optimize both the load coupling and the phase of the feedback.
- Output gaps in the tuning range with frequency jumping:
  Parasitic resonances in the circuit caused by long RF leads or unsuitable components for the frequency under consideration – the author thought he was being very good by using, for the 1 - 1.5 GHz oscillator, a 100 pF chip capacitor for the DC blocking to the transistor base because it was exactly the same width as the stripline. The result was a reverse tuning with a hysteresis point around 1.15 GHz – the self-resonant frequency of the chip capacitor. The problem was solved by replacing the chip capacitor with a simple disc capacitor.

## 6. CONCLUSION

With these few examples, relatively little outlay and using standard components from the television technology, tunable test oscillators may be made to cover the range 100 MHz to 2 GHz. Besides their application for the testing and alignment of antennas and filter networks, they can be used as the basis for a simple spectrum analyzer or a sweep generator.

EUROCARD

You can now order magazines, kits etc. using your **Eurocard** or **VISA Credit Card !**
We only require the order against your signature, the card number and its expiry date.

VHF COMMUNICATIONS / UKW-BERICHTE

VISA